Method for Dynamic State Monitoring of Pressure Vessel

Xuerong MA
Pressure Vessel Testing Center, P.O.Box 211, Mianyang, Sichuan 621000, P.R. China
Tel:+86-816-2466731,Fax:+86-816-2466728
E-mail:maxuerong827@163.com

Abstract

The life prediction is to estimate the life while the flaw initial size and critical size are knows. On the contrary, the life control is to estimate the flaw initial size at the predetermined life. Nondestructive test would be used to detect the flaws whose sizes are bigger than the allowable initial size estimated by the method, and corresponding repair or replacement of parts or components would insure the reliability and safety of structure in its lifetime. Aiming at this problem, the fixed amount relation between undetected probability of flaw of in service pressure vessel and the independence examination times is established in the base of examination results before. The ability of nondestructive testing is availably increased, the undetected probability of flaw of in service pressure vessel is controlled within the scope of an enough low and safe level. dynamic state monitor is realized.

Key words: life control, pressure vessel, nondestructive test, safety, dynamic state monitoring, reliability

1 Introduction

Usually, the product's inspection period is assuranced according to estimate life, but it could be appointed according to effective demand in engineering usually,that is, appointed life in advance, realization life control.For example, for the sake of the easy to management, pressure vessel, boiler, pressure piping, elevator, derrick, play special kind equipmentses, such as facilities and passenger transportation cableway...etc. are inspected according to department concerned in all countries of inspection period. On the other words, their inspection period isn't based on estimate life but is in advance appointed.Under the circumstance that this kind of inspection period in advance appointed, estimate life method already can't assurance its structure safety.In addition, for the structure part close of,difficult to open or dismantle, generally, inspection period requests langer possibly on the engineering.But for those easy to inspect, inspection period can be a little bit short. To this, ducment[1] carried on a research and put forward a idea and method of life control, makeing life research from estimate to active control. The flaw leaking to check is one of the main reasons to pressure container, airplane and launch machine etc. importance machine occurrencing trouble of. Relevant investigate data enunciation, because of structure material failing to result in of majior accident, caused by the flaw leaking to check above 80%.In the last years, though the nondestructive test technique had a very big development, but the results still existence bigger difference when dissimilarity examination personnel carry on examination to same crack, and can't examine out the flaw bigger than provision size in structure material.The indetermination of this kind of examination result is subjected to material, structure shape and size, examination equipments, examination environment, crack position and tropism, examination personnel's technique level and mental state appearance etc. many factor of influence.The flaw inspection out probability ,the nondestructive test reliability had carried on research by document[1 ~ 6].On this foundation, aiming at the realm of overall periodical examination in service pressure, how to select and combine the method

etc.to attain superior aspect, make further try, and put forward a concept of dynamic state monitor in this paper. Superior the overall periodical examination in the future,being conducted to the past periodical examination results, make it result that the possibility declines to the lowest in because of leaking check the flaw bigger than critical size appearance to pressure container, attaining that safety life can be controled.

2 Life Control Square Pattern

2.1 Life control square pattern containing varieties hurt

To set up $(D_{01}, D_{02}, \mathrm{L}\ , D_{0n})$ as initial hurt, $(D_{c1}, D_{c2}, \mathrm{L}\ , D_{cn})$ as critical hurt,t as the product life, Their existence as follows relation.

$$t = f(D_{01}, D_{02}, \mathrm{L}\ , D_{0n}\ ;\ D_{c1}, D_{c2}, \mathrm{L}\ , D_{cn}) \qquad (1)$$

When initial hurt $(D_{01}, D_{02}, \mathrm{L}\ , D_{0n})$ and critical hurt $(D_{c1}, D_{c2}, \mathrm{L}\ , D_{cn})$ known, to request product life, is called life estimate. On the contrary, the life control is to estimate the flaw initial size at the predetermined life t_0.

$$t_0 = f(D_{01}, D_{02}, \mathrm{L}\ , D_{0n}\ ;\ D_{c1}, D_{c2}, \mathrm{L}\ , D_{cn}) \qquad (2)$$

critical hurt $(D_{c1}, D_{c2}, \mathrm{L}\ , D_{cn})$ as known, (2) pattern is called as life control square pattern containing varieties hurt, it separate the $(D_{01}, D_{02}, \mathrm{L}\ , D_{0n})$ into two parts as Ω and $\bar{\Omega}$, $(D_{01}, D_{02}, \mathrm{L}\ , D_{0n}) \in \Omega$, $t \le t_0$, while $(D_{01}, D_{02}, \mathrm{L}\ , D_{0n}) \in \bar{\Omega}$, $t > t_0$. For the sake of assurance product life $t > t_0$, the methods of nondestructive test credibility have to adopt to check out product's initial hurt $(D_{01}, D_{02}, \mathrm{L}\ , D_{0n})$ belong to Ω, and fixing or replacing componentsin time, thus assurance the product is safety in the period of life appointedly.

2.2 Staple life control square pattern

For the single hurt of circumstance, in addition to with the form of type(1), for example, compound material's rigidity decline formula and the small crack $a - t$ formula etc..The most in common used on the engineering is still with the formula of hurt velocity token.

$$\frac{\mathrm{d}D}{\mathrm{d}t} = f(D, m, \sigma, \lambda) \qquad (3)$$

In the formula D as hurtfactor , m as material factor , σ as load factor , λ as environment factor. D can be a flaw size a, rusty of pressure container's wall etc..Carry on integral calculus to the formula (3), a life estimate formula can be get immediately

$$t = \int_{D_0}^{D_c} \frac{\mathrm{d}D}{f(D, m, \sigma, \lambda)} \qquad (4)$$

In the formula D_0 as initial hurt, while D_c as critical hurt. If the product life t_0 in advance appointed will be substituted into the formula (4),then the following life control square pattern can be get

$$t_0 = \int_{D_0}^{D_c} \frac{\mathrm{d}D}{f(D, m, \sigma, \lambda)} \qquad (5)$$

Initial hurt D_0 can be solved according to the formula (5),then the methods of nondestructive test credibility adopt to check out product's hurt bigger than D_0, and fixing or replacing components in time, thus assurance the product is safety in the period of life appointedly. For example, to stress rusty life control:

Stress rusty flaw extend formula as [4]

$$\frac{\mathrm{d}a}{\mathrm{d}t} = f(K_{\mathrm{I}}) \qquad (6)$$

In the formula

$$f(K_{\mathrm{I}}) = \begin{cases} C_1 + C_2 K_{\mathrm{I}} & K_{\mathrm{ISCC}} < K_{\mathrm{I}} < K_{\mathrm{IP}} \\ C_3 & K_{\mathrm{IP}} \le K_{\mathrm{I}} \le K_{\mathrm{IR}} \\ C_4 K_{\mathrm{I}}^{m} & K_{\mathrm{IR}} < K_{\mathrm{I}} < K_{\mathrm{IC}} \end{cases} \qquad (7)$$

C_1、C_2、C_3、m and K_{ISCC}、K_{IP}、K_{IR} as material and mediums system factor. If the product life t_0 in advance appointed,then the following stress rusty life control square pattern can be get

$$t_0 = \int_{a_0}^{a_c} \frac{\mathrm{d}a}{f(K_{\mathrm{I}})} \qquad (8)$$

In the formula a_c is critical flaw. initial flaw a_0 can be solved according to the formula (8),then the methods of nondestructive test credibility adopt to check out product's flaw bigger than a_0, and fixing or replacing components in time, thus assurance the product is safety in the period of life appointedly.

3 POD Curve Function Theory

Base on the biggest similairity estimate principle, a crack geometry dimension as a, its check rate $\mathrm{P}(a)$ can use logistic function to descrip, the POD curve function:

$$\mathrm{P}(a) = \frac{\exp(\alpha + \beta \ln a)}{1 + \exp(\alpha + \beta \ln a)} \qquad (9)$$

In the formula , α,β as logistic function factor.

When a crack geometry dimension is bigger than a_0, its leak rate of one check can use logistic function to descrip:

$$\mathrm{P}_{\mathrm{M}}(a_0) = 1 - \mathrm{P}(a_0) = \frac{1}{1 + \exp(\alpha + \beta \ln a_0)} \qquad (10)$$

Because the true value $\mathrm{P}_{\mathrm{M}}(a_0)$ can't be requested, so, on the engineering what to use is the confidence as γ of $\mathrm{P}_{\mathrm{M}}(a_0)$ the once-sided confidence upper limit $\mathrm{P}_{\mathrm{U}}(a_0)$, that is

$$\mathrm{P}[\mathrm{P}_{\mathrm{M}}(a_0) \le \mathrm{P}_{\mathrm{U}}(a_0)] = \gamma \qquad (11)$$

It can beproved that,to i th dangerou part make use of j th kind examination equipment to examine once, for the flaw bigger than a_0 , its confidence as γ the leak check rate confidence upper limit is

$$\begin{aligned} \mathrm{P}_{\mathrm{U}}(a_0) &= 1 - \mathrm{P}_{\mathrm{L}}(a_0) = 1 - \frac{\exp[\mathrm{y}_{\mathrm{L}}(a_0)]}{1 + \exp[\mathrm{y}_{\mathrm{L}}(a_0)]} \\ &= \frac{1}{1 + \exp(\hat{\alpha} + \hat{\beta} \ln a_0 - \mathrm{t}_{\gamma} \sqrt{\mathrm{S}_{\alpha} + 2\mathrm{S}_{\alpha\beta} \ln a_0 + \mathrm{S}_{\beta} \ln^2 a_0})} \end{aligned} \qquad (12)$$

In the formula , $\mathrm{P}_{\mathrm{L}}(a_0)$ showing its check rate lower limit

α and β estimation are $\hat{\alpha}$ and $\hat{\beta}$,and the calculation of variance S_{α}、$\mathrm{S}_{\beta\mathrm{i}}$ and covariance $\mathrm{S}_{\alpha\beta}$ can refer document[3],

$$\mathrm{Y}_{\mathrm{L}}(a_0) = 1 + \exp(\hat{\alpha} + \hat{\beta} \ln a_0 - \mathrm{t}_{\mathrm{r}} \sqrt{\mathrm{S}_{\alpha} + 2\mathrm{S}_{\alpha\beta} \ln a_0 + \mathrm{S}_{\beta} \ln^2 a_0}),$$

$$t_r = \mu_r \Big/ \sqrt{(1-\frac{1}{4\nu})^2 - \frac{\mu_r^2}{2\nu}}$$, μ_γ can be obtained by data[3]

$\nu = \sum_{i=1}^{j} n_i - 2$, n_i shows the check times of the same scale flaw, j shows one group's flaw numbers checking.

4 Least Independent Check Times Calculation

If through K times independent nondestructive test, the flaw leak check all rate $P_M(a_0)$ can be requested by the following method of big in provision size a_0, namely

$$P_M(a_0) = \frac{1}{[1+\exp(\alpha+\beta\ln a_0)]^K} \tag{13}$$

The confidence as γ of $P_M(a_0)$ the once-sided confidence upper limit $P_U(a_0)$, namely

$$P_U(a_0) = \frac{1}{\{1+\exp[y_L(a_0)]\}^K}$$

$$= \frac{1}{[1+\exp(\hat{\alpha}+\hat{\beta}\ln a_0 - t_\gamma\sqrt{S_\alpha + 2S_{\alpha\beta}\ln a_0 + S_\beta \ln^2 a_0})]^K} \tag{14}$$

In a siminar way, if adoption q kinds dissimilar flaw detector to the same dangerous part carrying on independent examination, the flaw check all rate $P_M(a_0)$ of big in provision size a_0 is

$$P_M(a_0) = 1 - P_D(a_0) = \prod_{i=1}^{q} \frac{1}{[1+\exp(\alpha_i+\beta_i\ln a_0)]^{K_i}} \tag{15}$$

The confidence as γ of $P_M(a_0)$ the once-sided confidence upper limit $P_U(a_0)$, namely

$$P_U(a_0) = \prod_{i=1}^{q} \frac{1}{\{1+\exp[y_{Li}(a_0)]\}^{K_i}}$$

$$= \prod_{i=1}^{q} \frac{1}{[1+\exp(\hat{\alpha}_i+\hat{\beta}_i\ln a_0 - t_\gamma\sqrt{S_{\alpha i} + 2S_{\alpha\beta i}\ln a_0 + S_{\beta i}\ln^2 a_0})]^{K_i}} \tag{16}$$

It can be saw from above various formula, by increasing independent examination times K or K_i the flaw leak check all rate can be reduced obviously to examination object.

For in advance provision of leak check all rate P, the flaw bigger than the size a_0 on the container, the independent nondestructive test times K of its leak check all rate not exceed P can from (16) formula's conversion, namely

$$K = \frac{-\ln(1-P)}{\ln\{1+\exp[y_L(a_0)]\}}$$

$$= \frac{-\ln(1-P)}{\ln[1+\exp(\hat{\alpha}+\hat{\beta}\ln a_0 - t_\gamma\sqrt{S_\alpha + 2S_{\alpha\beta}\ln a_0 + S_\beta\ln^2 a_0})]} \tag{17}$$

In a siminar way,if adoption kinds of dissimilar flaw detector to check, the flaw bigger than the size a_0 on the container, the independent nondestructive test times K of its leak check all rate not exceed P can from (16) formula's conversion. At this time satisfy the condition of K_1, K_2,Λ, K_q there are varieties dissimilar combination, one of them can be toke according to concrete circumstance. If calculation of value not integral, it can be toke commendable big of minimum integral as the best independent examination number of times.

5 The Best Examination Number of Times Analysis of the Air Tanks

The flaw leak check all rate as P of tanks in series mode, then each bottle should be controlled to leak check all rate Pi, under the circumstance that each set add power factor sime together(each bottle leak check all rate control equal importance), there is a relation like bellow in document [1,3] :

$$P = \frac{1}{M}C_M^1 y - \frac{1}{M^2}C_M^2 y^2 + \frac{1}{M^3}C_M^3 y^3 + \Lambda + (-1)^{M-1}\frac{1}{M^M}C_M^M y^M \quad (18)$$

$$P_i = y/M \quad (19)$$

Substitute the concrete numbers of bottle set container and the integral blaw false dismissal probability level needing to control, the false dismissal probability Pi of singal one among them can be requested immediately.

Substitute the false dismissal probability Pi of singal one needing to control requested from diffrent flaws false dismissal probability controlled and the biggest initial crack under diffrent life control, independence examination number of times need of can immediately get to assurance the flaw false dismissal probability control of bottles(set).

$$P = \prod_{i=1}^{q} \frac{1}{\{1+\exp[y_{Li}(40)]\}^{K_i}} \quad (20)$$

Tab.1 Test scheme for high and mid-pressure tanks at predetermined period of 5 years ($\gamma = 95\%$ $POD = 99\%$)

Kind of tanks	the combination mode and independent times of nondestructive tests		
	X-ray	UT	MT
33 tanks	1	1	1.5
14 tanks	/	2	2
3 tanks	/	1	1

In fact, along with the increment of the crack size,the harmfulness of the increment of its length to safety increases more and more small.But generally, along with the increment of the flaw size, no matter which of examination method, its checkable rate would be raised. But actually, the length of flaw bigger, usually its oneself height also bigger. Therefore, the check indetermination degree of the flaw's checkable rate and itself size fixed amount check should be controlled dialectically.

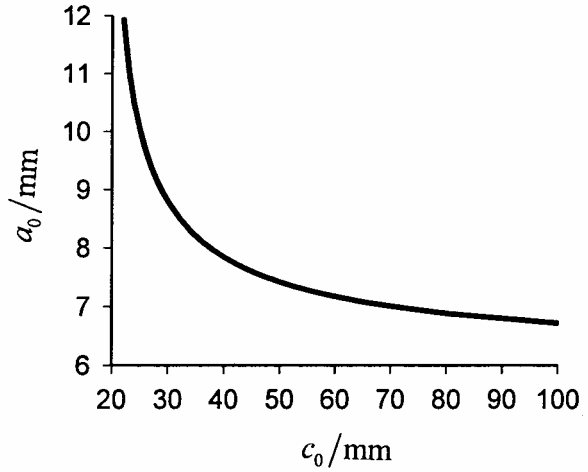

Fig. 1 The allowable curve for 16Mn steel of mid-pressure tank at predetermined period of 5 years

6.Conclusion

1) The dynamic state monitoring method in the service pressure within period examination had be put. Through checking the flaw bigger than initial one of enactment safety life adopting nondestructive test reliability way, maintaining or replacing to correspond spare parts in time, thus the whole structure in appointedly

life spanning the period is safety insurely.

2) Through the best independence examination number of times settle with nonstructive test combination project usage, the nonstructive test ability can be raised availably, under the circumstance that not increasing examination workload, the false dismissal probability of crack is able to control in a enoughly lowly of the safety scope, to insure with the life control period the bottles circulating safety.
3) Through the best independence examination number of times settle with nonstructive test combination project usage,it can provide science basis and power to the examination craft draw of bottle, examination method technique improvement, the safety usage, management,maintain and replace, provids science basis and instruction, and a dynamic state monitoring can be attained.

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